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Laboratory study on the cooling effect of flash water evaporative cooling technology for ventilation and air-conditioning of buildings

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ABSTRACT
This paper presents a simple cooling technology using flash water evaporation. The technology combines a water atomizer with a plate heat exchanger used for heat recovery of a ventilation system. It is mainly used to cool the ventilation airflow from outdoors and is particularly suitable to be used in warm/hot and dry environment where dehumidification of outdoor air is not needed. A laboratory experiment was designed and conducted to evaluate the cooling effectiveness of this technology. The experiment was conducted in a twin-climate chamber. One chamber simulated warm/hot and dry outdoor environments and the other simulated an air-conditioned indoor environment. The flash water evaporation cooling device was installed in the chamber that simulated indoor environment. The air from the chamber simulating outdoor environment was introduced into the cooling device and cooled by the flash water evaporation. Two outdoor summer climates were simulated in the study, i.e. the design summer climate of Las Vegas and the extreme summer climate of Copenhagen represented hot/dry and warm/dry climates. The results showed that the flash evaporative cooling technology, a simple and green cooling technology, is effective for ventilation and air-conditioning in warm/hot and dry climate zones. The technology can provide fresh outdoor air with a temperature of 4 to 7 °C lower than room air temperature.

KEYWORDS: Indirect evaporative cooling, heat recovery, water atomizer and Ventilation

INTRODUCTION

In modern buildings, most of the energy consumption of HVAC is used for conditioning the outdoor air supply for ventilation. Ventilation is important to maintain good air quality indoors that is essential for heath and comfort of occupants. Most of the air-conditioning systems use electricity to drive compression cooling devices. The power generation processes usually involve in the generation of greenhouse gas and the most of the refrigerants have high global warming potential (GWP). All of them contribute to the global warming.

In Europe, heat recovery is widely used in mechanical ventilation systems to recover the energy from the exhaust air. The existing air to air heat recovery technologies can be classified into two categories, i.e. sensible heat recovery and total heat recovery (enthalpy recovery), (ASHRAE 2004). Typical heat and enthalpy exchange efficiencies range from 55% to 80% (Dieckmann et al. 2003). The sensible heat recovery technology employed a heat exchanger that exchanges sensible heat between incoming outdoor air and the exhaust indoor air. The best counter-flow sensible heat exchange technology can recover 80% to 85% sensible heat (temperature efficiency) from the exhaust air (Klingenburg Catalogs, 2016).

Such heat recovery technology is suitable especially for winter application when the heating load is mainly sensible heat.

In summer season, especially in the hot and humid climate where dehumidification produces the major cooling load, enthalpy recovery is needed. However in the area where summer climate is warm and dry, the sensible heat recovery could also be used for ventilation. The enthalpy recovery technology using flash evaporative cooling was studied in the Centre of Indoor Environment and Energy (ICIEE) at the Technical University of Denmark (Fang et al. 2015) where the enthalpy efficiency of a counter flow heat exchanger combined with the flash evaporative cooling technology reached 70% for air-conditioned environment with warm and humid outdoor climate. The same study also observed the temperature efficiency of the same technology used as an indirect evaporative air cooling device when operating at warm/hot and dry outdoor environment. The experiment discovered a very high temperature efficiency of the technology. The study showed that flash evaporative cooling technology combined with counter flow air to air heat exchanger may partly or fully replace vapor compression cooling for air conditioning. This technology is low cost and completely green. This paper reports the experimental study and the results of the cooling effect of the flash evaporative cooling technology used in warm/hot and dry climate.

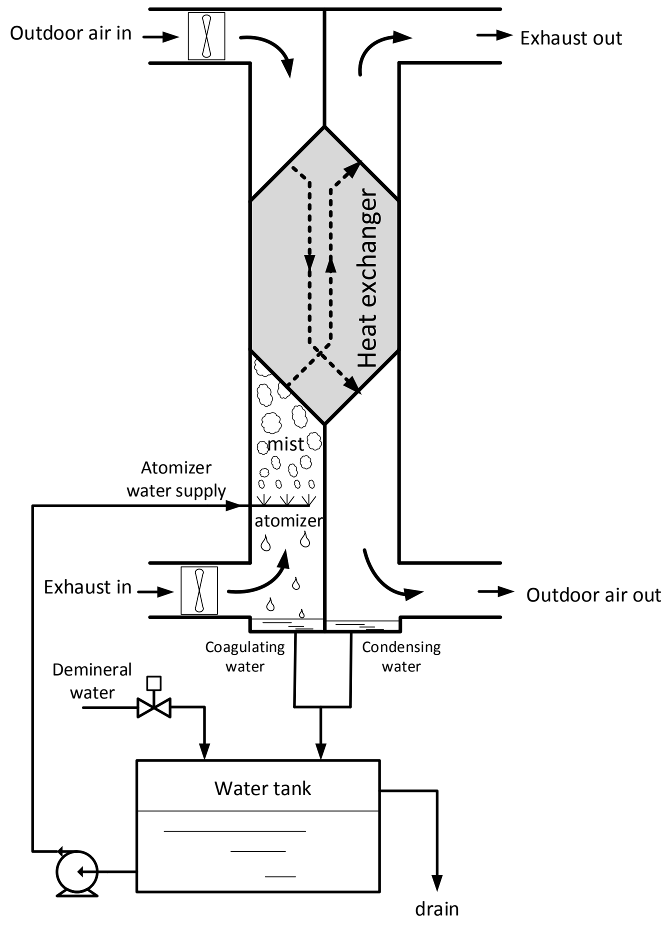

Figure 1. Principle of the developed total heat recovery unit.

METHODS

Design of the flash evaporative cooling device

The design of the flash evaporative cooling device is shown in Figure 1. It includes a counter flow air to air heat exchanger, an ultra-sonic atomizer and a water supply and collection system. The exhaust indoor air is first humidified by an ultra-sonic atomizer. The ultra-sonic atomizer breaks water into huge amount of ultra-fine water droplets – the ultra-fine water mist. Due to the evaporation of atomized water, the temperature of the exhaust air is cooled down to its wet-bulb temperature. At the same time, the exhaust air is saturated. Since the atomized water is more than what is needed to saturate the exhaust air, large quantity of the surplus ultra-fine water mist is carried by the exhaust air and enters the heat exchanger. Inside the heat exchanger, the ultra-fine water droplets absorb the heat that is transferred from the incoming outdoor air and evaporate immediately. The incoming outdoor air exchanges heat with the exhaust indoor air that carries ultra-fine water mist at its wet-bulb temperature. The heat exchange due to the temperature difference and water evaporation of the ultra-fine water mist cools the incoming outdoor air into wet-bulb temperature of the indoor air which could be many degrees lower than the indoor air temperature. Thus the ventilation outdoor air can be used to cool indoor environment that reduces the cooling demand for ventilation.

The water collecting system collects the surplus atomized water coagulated in the heat exchanger and the condensed water from the incoming outdoor air, if any, for recycling.

Experimental set-up and design

The performance of the designed flash evaporative cooling device was tested in a twin-climate chamber. One chamber simulated warm and dry outdoor climate and the other simulated an air-conditioned indoor climate. A test rig of the flash evaporative cooling device was developed as shown in Figure 2. The test rig include a counter flow heat exchanger, an ultra-sonic atomizer, a water supply and collecting system, air channels with a supply and an exhaust fan, airflow control system, four temperature and humidity sensors installed on the inlet and outlet of both sides of the heat exchanger and a data acquisition system to log all the data collected in the experiment. The test rig was installed in the climate chamber that simulated indoor climate condition and the exhaust air supply of the heat exchanger was taken directly from that chamber. The outdoor air supply of the heat exchanger was taken from the other chamber simulating outdoor climate conditions.

The experiment was designed to study the technology applied in the Danish summer climate (mild warm and dry climate) and the Las Vegas summer climate (hot and dry climate). For the Danish climate, the study was conducted in three indoor climate conditions and the extreme outdoor summer climate condition of Copenhagen as shown in Table 1. For the Las Vegas climate, the study was conducted in one indoor climate condition and one design outdoor summer climate condition as shown in Table 2. For the study in both Copenhagen and Las Vegas climate conditions, the experiments were conducted at three levels of air flow rate, i.e. the rated airflow rate of the heat exchanger (20L/s) and ±25% of the rated airflow rate (15L/s and 25L/s).

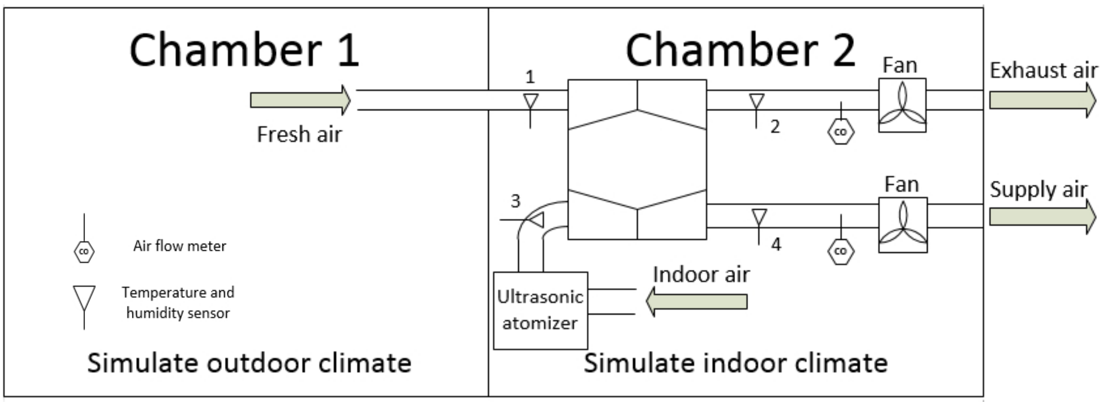

Figure 2. The experimental set-up.

Table 1. Experimental conditions at the simulated extreme summer outdoor climate of Copenhagen (30°C/40%RH)

Indoor climate conditions	Airflow rate (L/s)		
	15	20	25
25°C and 35% RH	X	X	X
25°C and 50% RH	X	X	X
25°C and 65% RH	X	X	X

Table 2. Experimental conditions at the simulated summer outdoor climate of Las Vegas (40°C/11%RH)

Indoor climate condition	Airflow rate (L/s)		
	15	20	25
25°C and 30% RH	X	X	X

Since the heat recovery of ventilation in summer of the two cities involves mainly in dry cooling of the outdoor ventilation airflow, temperature efficiencies was used to evaluate the effectiveness of heat recovery technology. The temperature efficiency was calculated using the following formula.

Temperature efficiency: $$\eta_t = \frac{t_{out}-t_s}{t_{out}-t_{in}} \tag{1}$$

Where:

η_t is the temperature efficiency;

t_{out}; t_{in}; t_s are temperatures of the outdoor air, indoor air and supply air (outdoor air after cooling by the heat exchanger).

RESULTS

Figure 3 shows the measured cooling effect of flash water evaporative cooling technology at the simulated extreme summer climate of Copenhagen. The temperature efficiency and the temperature of outdoor air after being cooled by the heat exchanger (the supply air temperature to the ventilated room) are presented at three levels of airflow rate in the heat exchanger and the experiment was repeated at three different levels of indoor humidity at 25°C.

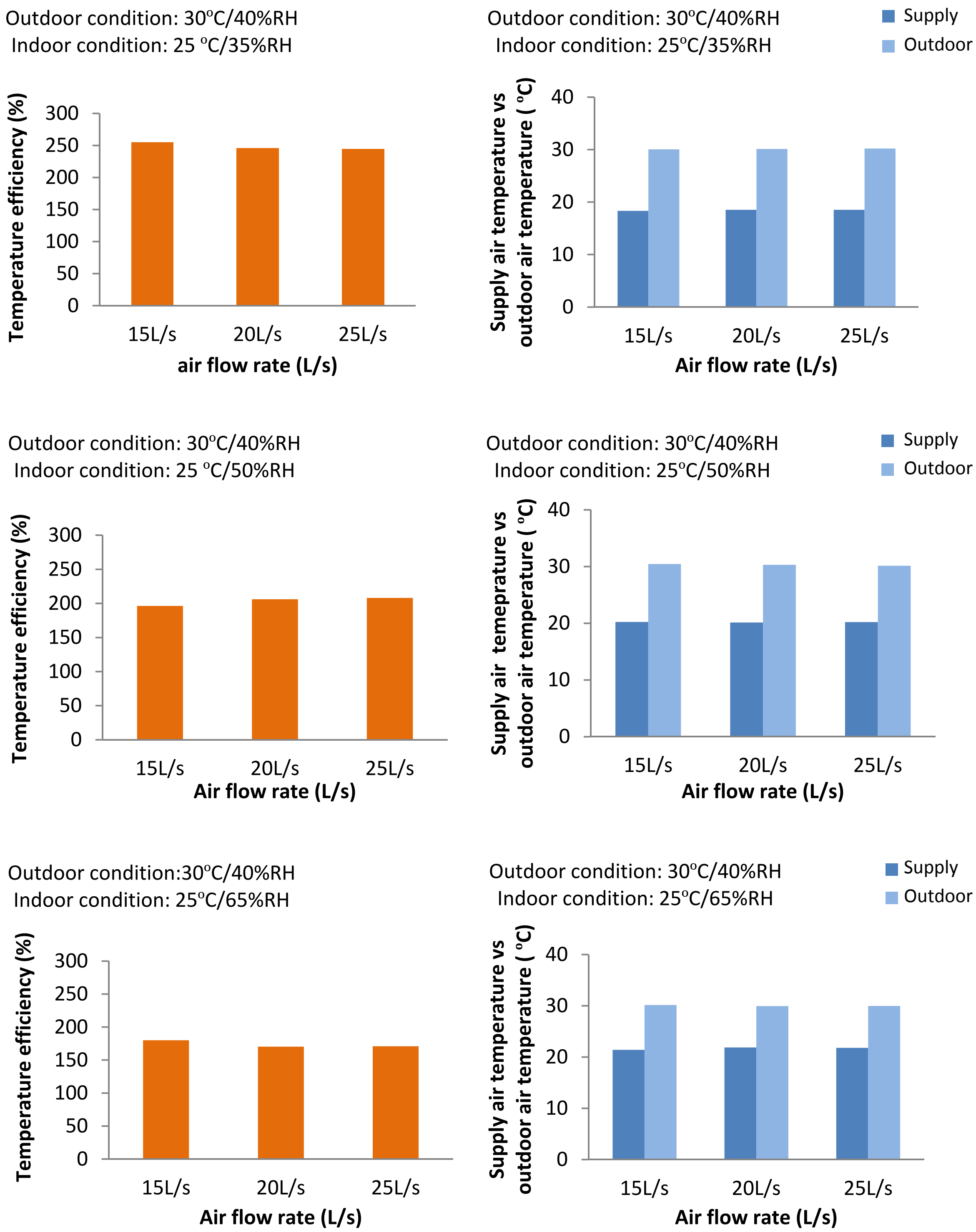

Figure 3. The measured temperature efficiencies and temperatures of supply and outdoor air at the three levels of airflow rate. The experiment was conducted at the simulated extreme Copenhagen summer climate and three air-conditioned indoor climate.

The measured cooling effect of flash evaporative cooling technology at the simulated summer climate of Las Vegas is shown in Figure 4. The temperature efficiency and the temperature of outdoor air after being cooled by the heat exchanger (the supply air temperature to the ventilated room) are presented at three levels of airflow rate in the heat exchanger.

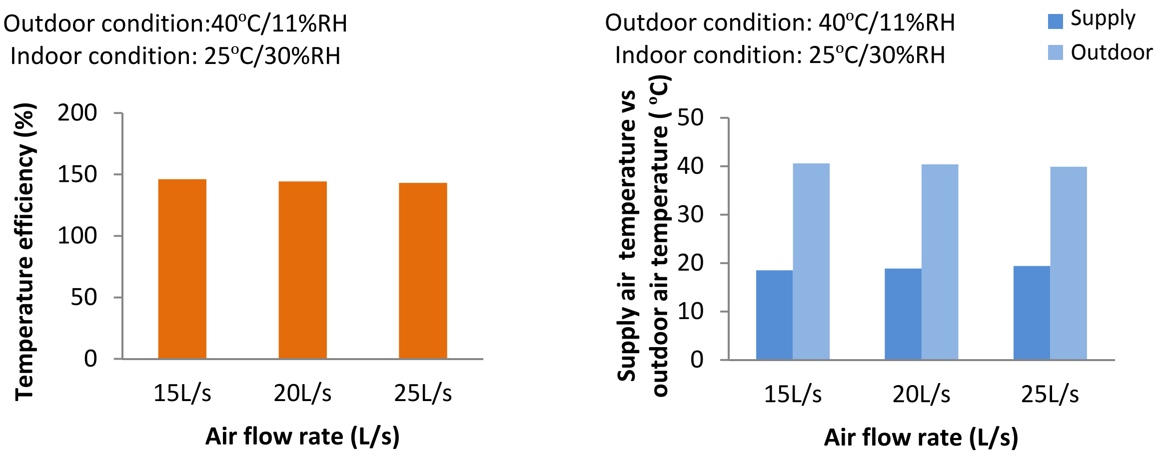

Figure 4. The measured temperature efficiencies and temperatures of supply and outdoor air at the three levels of airflow rate and environmental conditions of Las Vegas summer climate.

DISCUSSION

Although the principle of indirect evaporative cooling is well understood, the practical approaches to achieve such cooling can be different and lead to significant different cooling effectiveness. The flash evaporative cooling technology utilized the rapid evaporation of ultra-fine water droplets to intensify the evaporative cooling. The results of this experiment showed that all temperature efficiencies measured at the two summer climate conditions tested were above 100%. This was because that the heat exchanger was not only used to recover the sensible heat from exhaust air but also provided additional cooling for the outdoor supply air resulted in lower temperature of the supplied outdoor air than that of indoor air. The higher temperature efficiency observed the stronger cooling effect obtained to cool the supplied outdoor air. Compared to the existing indirect evaporative cooling technology using water spray, wet filter or other wetted media, the flash evaporative cooling technology has much higher cooling effectiveness because it requires much less water in the cooling process and the ultra-fine water droplets evaporate more efficient. The water mist used for the evaporative cooling can be controlled just enough for the cooling process. This will avoid additional cooling used to cool the excess sprayed water for the evaporative cooling.

The experiment was conducted at three different airflow rates, i.e. the rated airflow rate of the heat exchanger (20L/s) and ±25% of the rated airflow (15 and 25 L/s). The results showed that change of airflow rate around the rated airflow of the heat exchanger has almost no impact on the temperature efficiency of the flash evaporative cooling technology provided that sufficient micro-droplet mist is introduced into the exhaust airflow.

The experiment further showed that the temperature efficiency decreased with increasing indoor air humidity. Figure 5 compares the temperature efficiency and supply outdoor air temperature after the air was cooled by the heat exchanger at the three levels of indoor relative humidity tested. The results clearly showed that the supply air temperature increased with increasing indoor air humidity. This was due to the fact that the minimum temperature that flash evaporative cooling can reach is limited by the wet-bulb temperature of indoor air. Increase indoor air humidity results in the increase of its wet-bulb temperature. When indoor relative humidity increases to 100%, the effect of evaporative cooling disappears. However, in the warm and dry summer climate zones, indoor humidity of the most of office and residential buildings is well below 100% leaving sufficient room for the evaporative cooling effect.

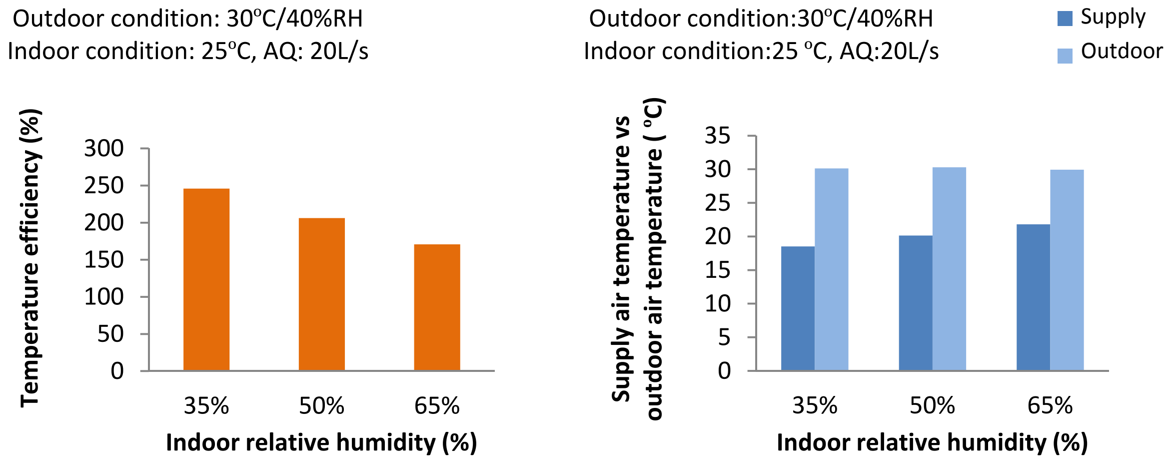

Figure 5. Comparison of temperature efficiencies and supply air temperatures at three levels of indoor humidity with the extreme Copenhagen summer outdoor climate.

The flash evaporative cooling technology is simple and effective. It is particularly suitable to be used in the warm/hot and dry climate zone for air-conditioning especially for the buildings that has already installed sensible heat exchangers in the ventilation system for the exhaust heat recovery. Considering its low cost and zero impact on environment, the flash evaporative cooling technology should have great potential in practice for air-conditioning.

CONCLUSIONS

The flash evaporative cooling technology, a simple and green cooling technology, is effective for ventilation and air-conditioning in warm/hot and dry climate zones. The technology can provide fresh outdoor air with a temperature of 4 to 7 °C lower than room air temperature.

ACKNOWLEDGEMENT

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